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ELECTRONIC POLARIZATION SWITCHING SYSTEM FOR AN X-BAND DUAL-CHANNEL CIRCULARLY-POLARIZED PRECIPITATION RADAR

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ABSTRACT

An electronic polarization switching system for the National Research Council X-band precipitation radar is described. The system, which utilizes a high-power switchable waveguide ferrite circulator, provides for rapid switching of the polarization of the radiated waves between orthogonal polarizations. These are usually selected to be right-hand and left-hand circular, but other pairs, such as vertical and horizontal polarizations may be chosen. The isolation between channels is 42dB minimum.

RÉSUMÉ

On décrit un système de commutation de polarisation électronique destiné au radar bande X de mesure des précipitations du Conseil national de recherches. Le système, qui comprend un circulateur à ferrite guide d'ondes commutable haute puissance, permet la commutation rapide d'une polarisation orthogonale à une autre. On choisit habituellement des polarisations circulaires à droite et à gauche, mais on peut aussi effectuer d'autres types de commutation, par exemple d'une polarisation verticale à une polarisation horizontale. L'isolation entre les voies est d'au moins 42 dB.

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1. INTRODUCTION

Dual-channel radar systems that have the capability for simultaneously measuring two orthogonally polarized components of the echo provide considerably more target information than one-channel radars, which yield only the reflectivity. Specifically, the ratio of co-polarized to cross-polarized echo intensities is also obtainable. If the system provides for the determination of the relative phase angle and the degree of correlation between the two orthogonal components, two additional target characteristics may be derived. For circularly-polarized dual-channel precipitation radars with cross-correlation detection capability, the additional target characteristics, termed polarization parameters, are related to the mean shape of the precipitation particles, to the degree to which a preferred orientation of the particles exists, and to the mean orientation angle of the particles (1).

The relationship of the polarization parameters to these geometric factors is direct in a special case, i.e., if (i) the illuminated particles are small compared to the wavelength so that Rayleigh scattering theory applies and (ii) there is an unobstructed propagation path so that no depolarization of the waves occurs between the radar and the echoing region. In general, however, these ideal conditions do not prevail. There is frequently progressive depolarization of the radar waves as they pass through a precipitation medium, and the echo is further depolarized on its return to the radar antenna. In addition, at short wavelengths, Rayleigh scattering may no longer prevail, and size-dependent differential phase shifts occur in the backscattering process. Both the progressive depolarization (the propagation effect) and the backscattering differential phase shift affect the measurement of the geometric characteristics of the scattering medium.

As will be shown below, under certain conditions, e.g., in uniform precipitation, the propagation effects and the backscattering differential phase shift can be separately determined if measurements are taken by sequentially transmitting right-hand circular (RHC) and left-hand circular (LHC) polarization. To be fully meaningful, the measurement cycle must be completed in a time interval short in comparison to temporal changes in the

storm structure, and repeated polarization switching is advisable not only for providing statistical averaging, but for the investigation of transient conditions such as lightning-induced changes in propagation conditions. Separation of the propagation effects from the backscattering effects is important both for studies of radio wave propagation in the atmosphere and for studies of remote sensing of the types of particles occurring in storms.

A waveguide ferrite switch has recently been fitted to the 3.1 cm polarization diversity radar operated by the National Research Council of Canada at Ottawa, Ontario. Concurrently, full duplexing of the second receiver channel has been instituted. This system provides for electronic switching of the transmitter output between left and right circular polarizations, while retaining the capability for simultaneous measurement of the radar return on the two senses of polarization. The system also includes the capability for switching between orthogonal linear polarizations, thus permitting measurement of the differential reflectivity. This report provides background information and technical data pertaining to the polarization switching system. Part of this information has been presented elsewhere in a paper which also contains some preliminary results (2).

2. THEORETICAL CONSIDERATIONS

For two-channel circularly-polarized radars, the following equation, which is derived and discussed more fully elsewhere (1, 3), shows the interrelationship between the two circularly-polarized radar echoes (R_1 and R_2) and the atmospheric and scattering parameters:

$$[1] \qquad \left(\frac{W}{W_2}\right)_{\pm} = \left(\frac{\langle R_1 R_2^{*} \rangle}{\langle R_2 R_2^{*} \rangle}\right)_{\pm} = \rho \bar{\nu}_{\pm} e^{i(\bar{\delta} \pm 2\bar{\alpha})} + 2pe^{i(\chi \pm 2\tau)} + 2\bar{\varepsilon}_{\pm}$$

In Eq. [1], R_1 and R_2 are, respectively, the same sense (co-polar) and opposite sense (cross-polar) radar returns, where the reference sense is that of the transmitted wave. W_2, the main channel return, and W, the complex correlation between R_1 and R_2, are time averages taken over a period long with respect to the reshuffling time of the precipitation particles. ν is the cancellation ratio for a single particle (negative for oblate particles, positive for prolates), and δ is the differential phase shift for circular polarization components. (δ is related to Δ, the backscatter differential phase shift for linear polarization components by $\tan \Delta = 2\nu(1 - \nu^2)^{-1/2} \sin \delta$ (4).) ρ, α, and τ are, respectively, the degree of preferred orientation of the particles, the orientation angle of the particles within a cell, and the orientation angle of the anisotropy axis of the medium. $pe^{i\chi} = \tanh(\Delta\gamma L/2)$ is the complex circular depolar-

ization, $\Delta\gamma$ being the differential propagation constant of the precipitation medium. ε is an antenna error term. The + and - signs, following convention, denote RHC and LHC polarizations, respectively, and the overbars indicate averages over a population of particles. The hydrometeors, $\nu_+ = \nu_-$ if the particles are small (Rayleigh-sized). This equality also holds for larger particles if there is a plane of symmetry as seen from the radar.

The three terms on the right-hand side of Eq. [1] describe, respectively, scattering effects, propagation effects, and antenna errors. The latter, if stable and uniform, can be corrected in the computation. From inspection of Eq. [1] it is seen how polarization switching contributes to the measurement of the properties of the scattering medium. If measurements are taken sequentially at RHC and LHC polarization, the two resulting values of the scattering term contain the values of $\bar{\alpha}$ and $\bar{\delta}$, while the change in the argument of the propagation term is related to τ.

When the propagation term is negligible, $\bar{\alpha}$ and $\bar{\delta}$ may be obtained from

$$[2] \qquad \arg W_{\pm} = \bar{\delta} \pm 2\bar{\alpha} + \pi$$

i.e.,

$$[3] \qquad \bar{\alpha} = \frac{1}{4}\left[\arg W_+ - \arg W_-\right]$$

and

$$[4] \qquad \bar{\delta} = \frac{1}{2}\left[\arg W_+ + \arg W_-\right] - \pi$$

If W/W_2 is plotted on the complex plane for RHC and LHC data taken on uniform precipitation, the angular separation of the plots is 4τ.

3. PRACTICAL CONSIDERATIONS

A prime consideration in the application of switching to a dual channel system is the maintenance of a high level of isolation between channels. Cancellation ratios exhibited by highly symmetric precipitation particles may exceed 35 dB; meaningful measurements of all the polarization characteristics of such particles are only possible if the antenna system has excellent polarization purity throughout the beam and if care is taken to provide high isolation so that the amplitude and phase of the weak signal are not affected by leakage from the "main" channel. An antenna integrated cancellation ratio of over 40 dB, and channel-to-channel isolations in excess of 50 dB, at least for narrow bandwidths, permit such measure-

ments; however, the introduction of a ferrite switch can lower the isolation to the order of 25 dB unless measures are taken to reduce leakage.

Leakage through the switch results in the generation of an unwanted polarization component in the radiated field. Provided that the leakage is small and stable, it can be compensated for in the computation by the method previously used for correction of antenna errors. For the X-band radar, the "antenna error" factors are determined by taking data on light precipitation at vertical incidence. Under these conditions, W/W_2 should be zero. The residual values of this quantity are interpreted as being twice the "antenna error", and the appropriate corrections made in running the computation programs.

Commercially available ferrite switches do not ordinarily achieve the desired degree of inter-channel isolation; however, in our radar, the operating frequency is fixed, and narrow-band tuning of the switch, as described below, can be used to improve the isolation. Since the radar is pulsed, the pertinent isolation figures are those averaged over the spectrum of the signal. Values measured with a cw source will be higher, but are not representative of actual operating conditions. Because the spectral width of the radar pulse is not negligible, it is important to minimize the spacing between tuning elements and the switch, so that the bandwidth is not unduly restricted.

Although the primary interest is in switching between circular polarization states, there is also an interest in switching between horizontal and vertical linear polarizations for determination of the differential reflectivity (Z_{DR}), a factor which is widely measured in other laboratories. Partly for this reason, the manual polarization control (also termed the microwave circuit), which would be redundant if only circular polarizations were to be radiated, is to be retained. (The microwave circuit is also used for calibration, and as a back-up system.)

In contrast to switching systems for single channel radars, in which the same i-f and video amplifier chain is used for the two signals, dual-channel systems can suffer from differential gain variations, an effect which is particularly troublesome for Z_{DR} measurements. Stable amplifiers must be used, and means must be provided for measuring and checking the differential gain. In our system, for Z_{DR} work, the differential gain is established by taking observations with the antenna pointing vertically during stratiform precipitation. Under such conditions, the average value of Z_{DR} is zero, thus providing an overall system check. For routine checking, a 9.6 GHz cw signal from a calibration oscillator is injected into both feed lines at points close to the antenna. The outputs of this oscillator (shown in Fig. 1) have a fixed phase and amplitude relationship and allow calibration of the system except for the antenna reflector and feed.

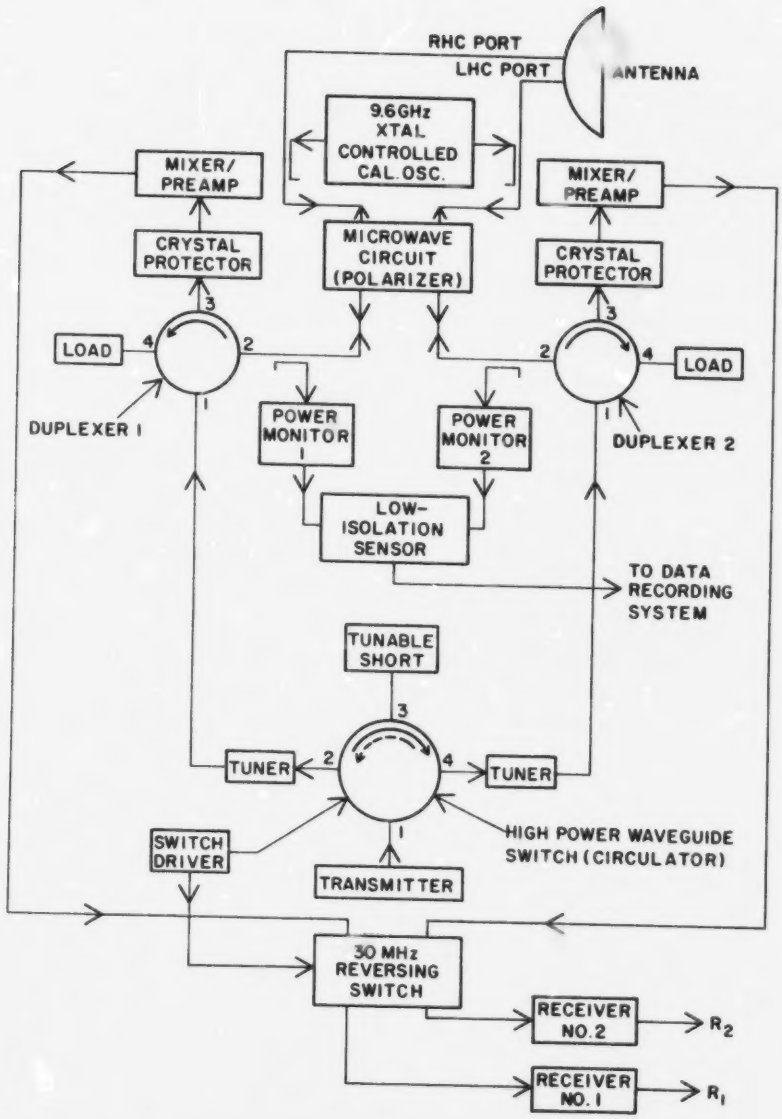

Figure 1. Polarization switching system in which received signals are switched at IF in synchronism with RF switching

4. DESCRIPTION OF WAVEGUIDE SWITCHING SYSTEM

We have considered two schemes for implementation of electronic switching in our radar system. In the first of these, which has been implemented, the waveguide switch operates on the transmitted signal only.

Switching of the received signals occurs concurrently, but separately, in the i-f circuitry so that the co-polar and cross-polar signals will always remain in their respective receivers. This is advantageous for dynamic range reasons as well as for simplification of computer programming. A more complex system in which both transmitted and received signals are switched at r-f in the same switch will be implemented later. The application of the first scheme to our radar system is outlined by the block diagram of Fig. 1.

The current system incorporates a high power latching ferrite circulator (Raytheon Model SXH20), which is capable of handling 280 kW peak power, has a switching (transition) time of 3 μs, and may be operated at a switching (cycling) rate of up to 1500 Hz. Its major limitation for this application is its isolation, which before being optimized for the radar frequency, was approximately 26 dB at 9.6 GHz. Its insertion loss is approximately 0.5 to 0.6 dB.

The two output ports of the switch (Ports 2 and 4) feed the radar duplexers, which are also ferrite circulators. The microwave circuit (polarizer) shown between the duplexers and the antenna is manually operated, and provides for the selection of any pair of orthogonal polarizations. In recent work, the manual microwave circuit has been used principally for selecting either linear or circular polarization pairs.

Since our radar operates at a fixed frequency with a stable magnetron, narrow band tuning devices were used to improve the inherent isolation of the switch. During system development, it was discovered that the narrow-band isolation performance could be significantly improved by lowering the supply voltages by an average of some 8% from their design values of ±15.0 VDC, a change which did not adversely affect any other characteristic. That change, in conjunction with the use of fixed tuners on the output lines, and a sliding short tuner on Port 3, yielded isolations of the order of 46 dB.

Maintenance of this degree of isolation in an operating system, subject to such conditions as fluctuating temperatures, voltage variations, cold start-ups, and irregular periods of observations interleaved with sometimes lengthy standby periods, was not possible. Therefore a more realistic value of 42 dB was set as an operational level. For cw signals, the isolation exceeds 42 dB over a bandwidth of 15 MHz minimum.

A decrease in isolation to below the 42 dB threshold is automatically detected by a sensing system which flags any data records taken under such circumstances. The sensor comprises the two power monitors shown in Fig. 1 in conjunction with threshold circuitry which generates a data bit whenever an excessive power level occurs in the "non-energized" waveguide. This

portion of the system is described more fully below. The isolation of the "tuned-up" system is quite stable, and in operation, only a very small number of the data records are flagged with the warning bit.

The switch does, however, have one additional characteristic which initially proved troublesome. When it is first powered up during a cold start, the switch isolation is generally quite low. Upon cycling, the isolation increases rapidly, reaching its peak value after about five or six cycles. It thereafter remains high as long as the switch is being regularly exercised. After a standby period, several cycles of operation are required to restore satisfactory isolation. In our system, where currently the polarization switching rate is 0.7 Hz or lower, good isolation is obtained by cycling the switch an odd number of times in rapid succession each time it is desired to alter the polarization state. This particular requirement will disappear when pulse-by-pulse switching is introduced.

For the present we are using sequential block switching, i.e., successive blocks of pulses are of orthogonal polarizations. Our current minimum block length is 1.4 s, but most results to date have been taken with a 2-s block length. The block length limitation is imposed largely by the settling time of the analog integrators used for averaging of the video signals, although further speedup of the existing system would soon be limited by the capability of the coaxial i-f reversing switch.

During polarization switching, large transient voltages appear at the receiver outputs. If these are not suppressed, the analog integrators used for signal averaging will produce erroneous results. Suppression of these transients is accomplished by briefly disabling the range gates, using a gate pulse interrupter circuit which is described later.

4.1 Interconnections to radar (Fig. 2)

The interconnections between the waveguide switch, its associated circuits as described in Sections 4.2 to 4.5, and various pre-existing parts of the radar system, are shown in Fig. 2. The mode control switches provide for a non-switching mode of operation which is basically identical to the previous operation in which the radiated polarization is adjusted manually by the microwave circuit (polarizer), with RHC, linear, and LHC polarizations produced at the designated stops on the manual mechanism. Care must be taken, however, to ensure that the i-f reversing switch is in the normal position when data is taken in the non-switching mode. Also, in this mode, the waveguide switch is still being driven by an even number of pulses so that good isolation is maintained; however, this action does not affect the operation. The non-switching mode is always used for taking receiver noise readings and for recording the offset voltages of the analog integrators.

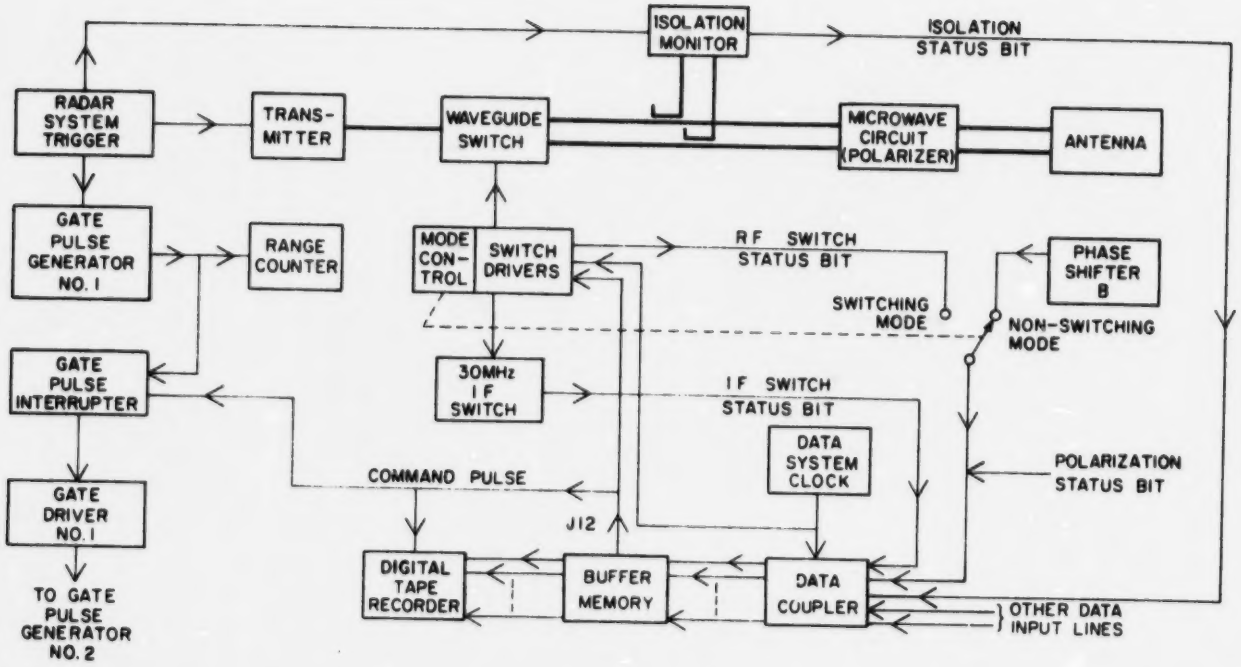

Figure 2. Interconnection diagram showing waveguide switch and associated circuits in relation to relevant parts of the radar system

In the switching mode, the source of the drive pulse for the waveguide switch is normally the buffer memory. (The tape recorder start command, terminal J12, is used.) However, optionally, the system clock can be used as the drive pulse source. This permits checking of the isolation as described in Section 4.3, without having to operate the tape recorder. In the switching mode, the manual microwave circuit (polarizer) is set at 270° (which is the LHC stop for the non-switching mode). The RF switch status bit automatically feeds the data coupler with the correct polarization status bit so that the same computer program can correctly determine the radiated polarization in both modes of operation.

4.2 Radar transmitting and receiving circuits (Fig. 3)

The high power ferrite switch is situated between the transmitter and duplexers. Transmitter power is switched between Line I and Line II by the high power ferrite waveguide switch. The isolation of the ferrite switch was about 26 dB when purchased. Since the overall radar system should have isolation over 42 dB, the switch had to be improved. At the radar frequency of 9.6 GHz, tests showed that improved isolation could be obtained with its power supply voltages set at -13.7 and +14.0 V. To further improve the system isolation, a five-pin tuner was placed on the output of each port. The fourth port was terminated with an adjustable short.

With the tuners inactive the adjustable short was moved to find the best combination of isolation on the two channels. Final isolation adjustments were made by using the tuners to reflect the correct power and phase from the high power port to the isolated port.

To set up and check the isolation of each channel, Line R of the polarizer is connected to an auxiliary line using the calibration switch. Next, the polarizer is set to deliver the transmitter output power to Line R. A -40 dB signal is coupled off and the remaining power is absorbed in a high-power flat load. The small signal is attenuated with a calibrated attenuator set for 50 dB attenuation. After detection, this signal is displayed on an oscilloscope to establish a reference level. The polarizer is then set to deliver the transmitted power to Line L, following which the isolation in one state of the high power switch may be determined with the calibrated attenuator. This procedure is repeated for the other state of the high power switch.

Two 20-dB couplers tuned for high directivity were placed in the waveguide lines after the duplexers. The two signals from these were detected and used to control the isolation detection circuits. To calibrate these isolation detection circuits, overall isolation can be adjusted with the moving short on the high power ferrite switch. The isolation is monitored

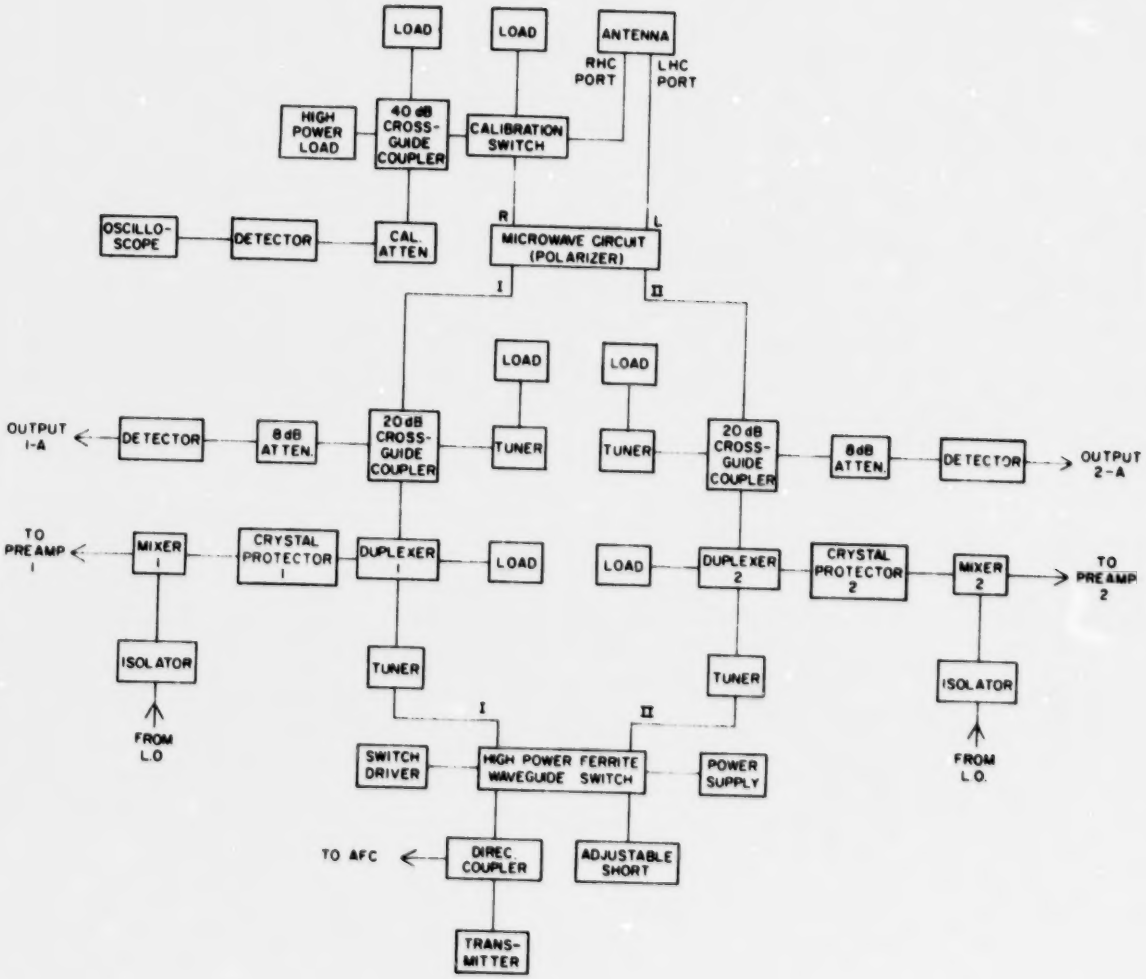

Figure 3. Block diagram of radar transmitting and receiving circuits showing elements necessary for set-up and performance testing of waveguide switch

on the attenuator and oscilloscope and the circuits adjusted to trigger at predetermined levels of signal.

4.3 Radio Frequency and Intermediate Frequency switch drivers (Fig. 4)

The timing pulse for this circuitry comes from the data recording system. When the recording system is not running, the clock pulse is used to check the isolation.

The timing pulse triggers the oscillator timing circuit, the output of which can be varied in width. This output is used to turn on an oscillator and produce a burst of pulses, either odd or even numbered, which is fed to a ÷2 circuit. When an odd number of pulses are divided by two, the RF switch which is actuated at each transition, ends in the state opposite to its initial state. These odd numbered pulses also drive the IF switch which, because of its slow response time, switches only once to the opposite state. The RF switch requires several rapid switches to maintain good isolation. When an even number of pulses are divided by two, the RF switch cycles, but now the end state is the same as the initial state. In this case, because of its slow response, the IF switch does not change state. The purpose of the even-numbered-pulse state is to allow the taking of data with fixed polarization while maintaining good isolation. These pulses also drive the coupler and data lights to record the state of the RF and IF switches.

4.4 Isolation monitor (Fig. 5)

This circuitry provides a means of telling visually and on tape if the isolation is the required 42 dB or better on one channel during switching.

The transmitter pulses are detected (see Fig. 3) and fed to a video amplifier. These amplified pulses go to a voltage comparator which gives an output pulse if the isolation is under 42 dB. This pulse is shaped and sent to the pulse sampler. The pulse sampler is clocked by the transmitter trigger pulse which has been shaped and delayed. If there is a pulse present from the voltage comparator at the sampling time, the sampler provides a "0" level which turns the light of the isolation display off thereby indicating low isolation. The logic level is also sent to the status bit coder. If no pulse is present from the voltage comparator at the sampling time the sampler provides a "1" level which turns the light of the isolation display on, indicating over 42 dB isolation. There are two of these identical circuits, one detecting at RHC and one at LHC, so that when the pulse is small in one circulator indicating good isolation (isolation display light on) the other circulator has the large transmitter pulse which will turn the isolation display light off. The status bit coder sends a

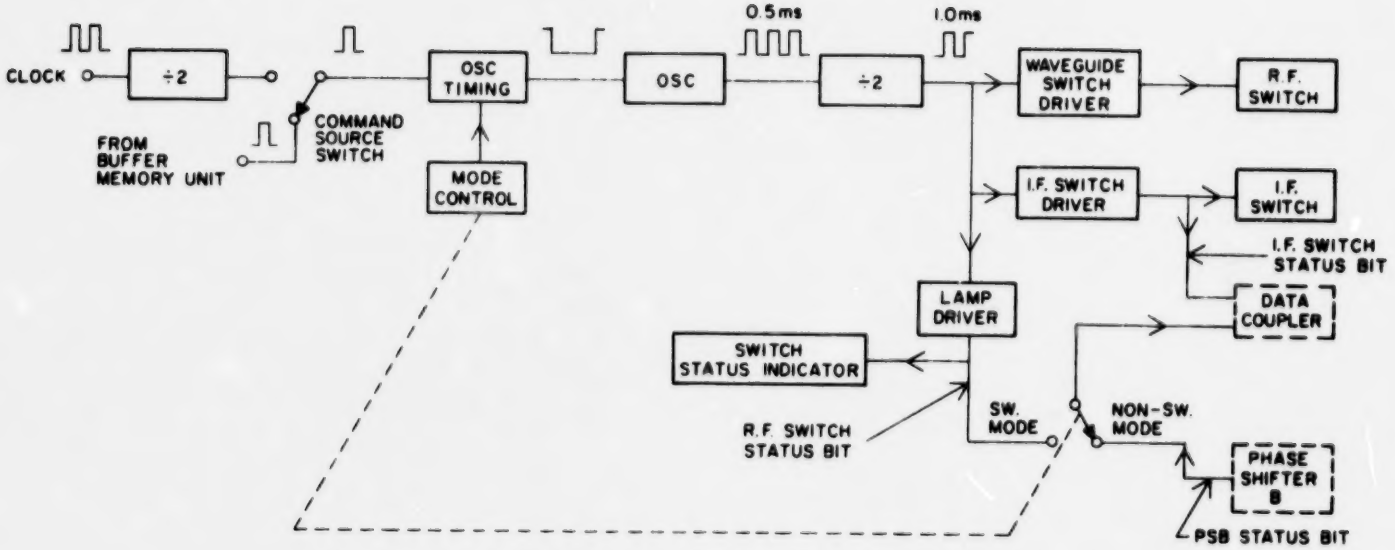

Figure 4. Radio frequency and intermediate frequency switch drivers

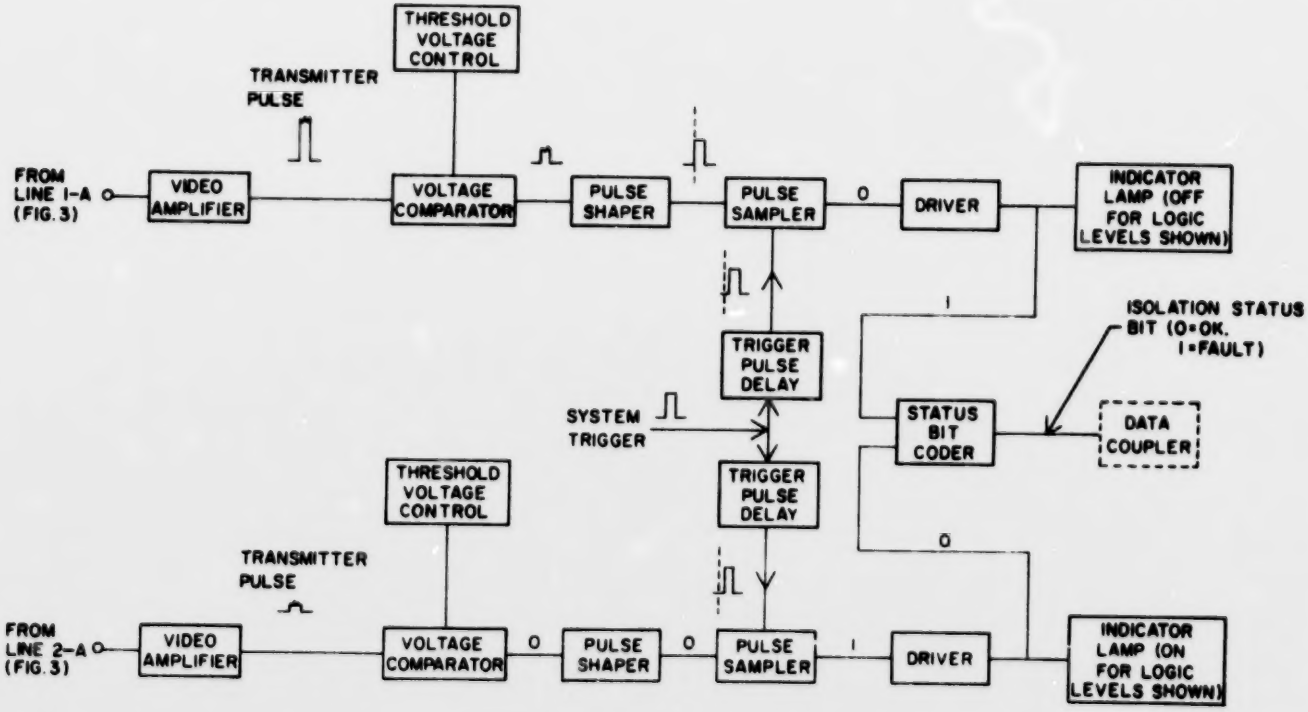

Figure 5. Isolation monitor

combined isolation status bit, which covers both channels, to the coupler. During operation the RF power is switched between the RHC port and LHC port.

One of the ports will always indicate the large transmitter pulse (isolation display light off). The other port will indicate the isolation (over 42 dB isolation, light on; under 42 dB isolation, light off).

4.5 Gate Interrupter (Fig. 6)

Since the IF switch has a slower response time than the RF switch, the sampling circuits must be disconnected during the switching time. This blocks the received signals until the IF switch has time to operate. This is accomplished by using a circuit called the gate interrupter.

The timing pulse is first inverted and then lengthened sufficiently to shut off the sampling circuits during the IF switching interval as shown in the block diagram.

4.6 Alternative switch configuration

The alternative system shown in Fig. 7 requires only one duplexer, and eliminates the need for an i-f reversing switch. However, to provide for independent adjustment of the isolations in the two channels for both transmitted and received signals, eight high-directivity couplers, six continuously-variable tuners, and two medium-power circulators are needed as shown. Devices A and B are, respectively, reflection-type and transmission-type tuners. Tuners A1 and A2 are used for nulling unwanted transmitted signals in the feed lines to the microwave circuit. Tuners A3 and A4 are used for nulling the co-polar returns which would otherwise reach Receiver 2, and Tuners B1 and B2 are used for nulling the cross-polarized returns which would appear at the output of Receiver 1. Pulse-by-pulse segregation of the received signals, prior to averaging, must be done electronically at video frequency by gating circuits, or by A/D converters under software control.

ACKNOWLEDGEMENT

The authors are indebted to L.W. Woods for assistance in the construction and installation of the apparatus required for the waveguide switching system.

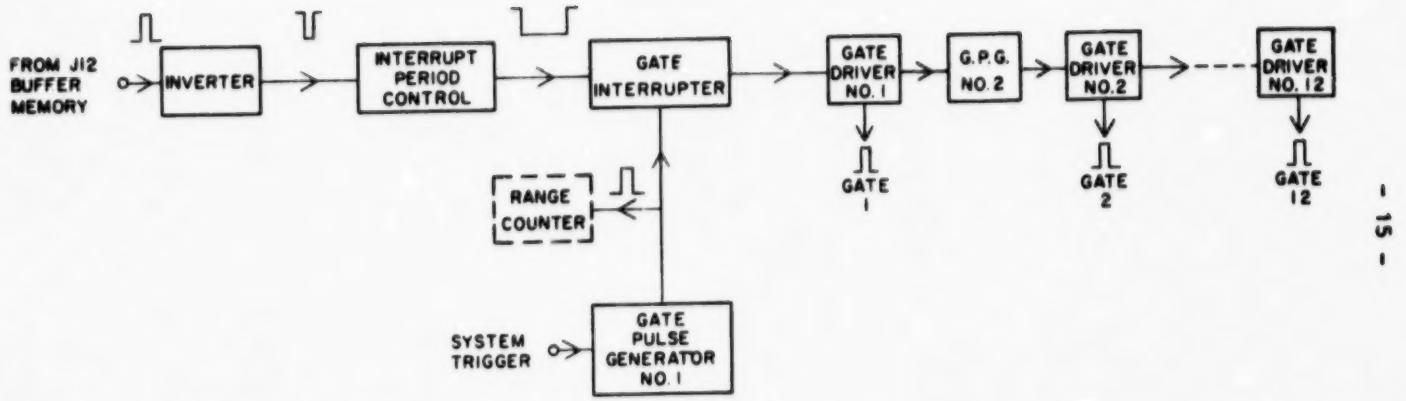

Figure 6. Gate pulse interrupter for suppression of transient signals

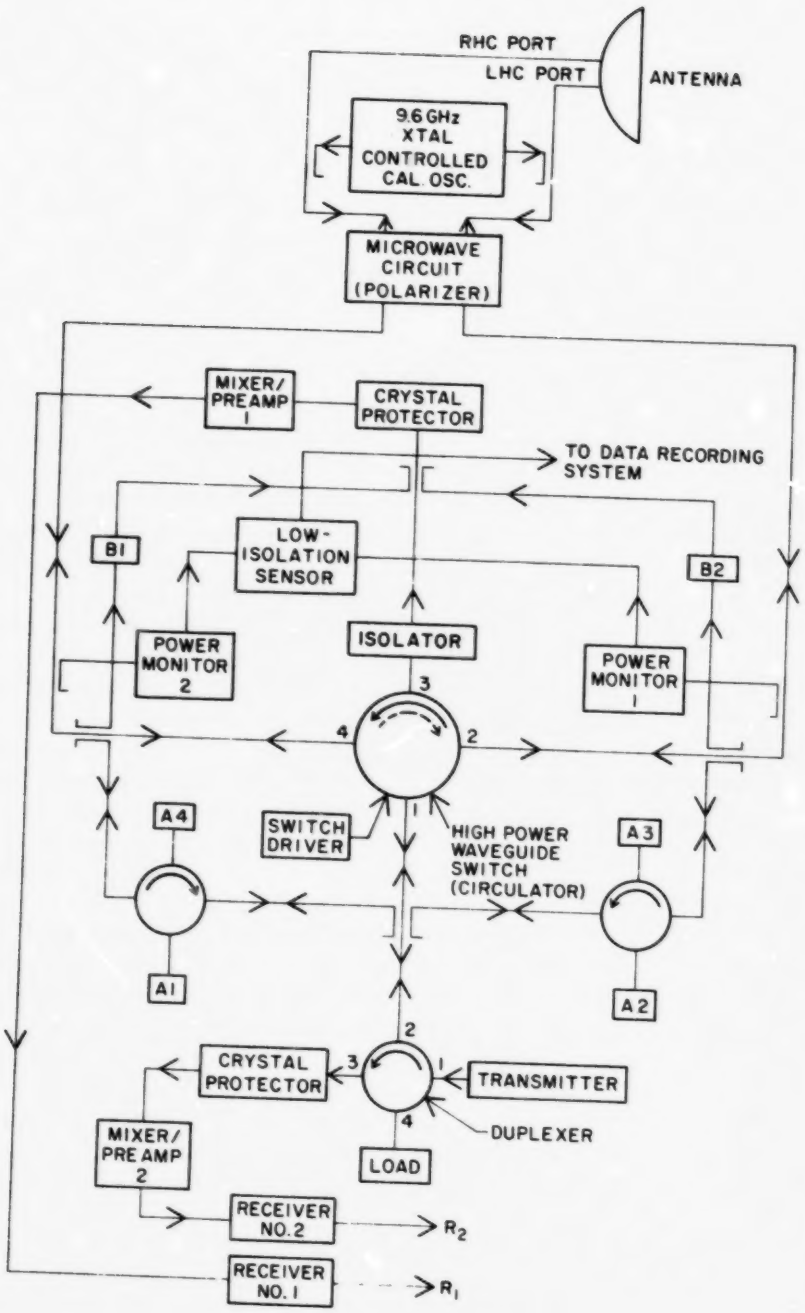

Figure 7. Alternative polarization switching system with RF switching of both transmitted and received signals in the same switch. Devices A and B are respectively reflection-type and transmission-type tuners. Each provides for continuous variation of amplitude and phase

REFERENCES

1. McCormick, G.C., and Hendry, A. Principles for the radar determination of the polarization properties of precipitation. Rad. Sci. 10(4): 421-434; 1975.

2. Hendry, A., Antar, Y.M.M., Allan, L.E., and Cook, P.R. Application of waveguide switching in dual-channel polarization diversity radar, and preliminary results. Preprints, 21st Conference on Radar Meteorology, Edmonton, Alta. September 19-22, 1983. American Meteorological Society, Boston, MA. pp. 352-357.

3. McCormick, G.C. and Hendry, A. Radar measurement of precipitation-related depolarization in thunderstorms. IEEE Trans. on Geosci. Electron. GE-17(4): 142-150; 1979.

4. Allan, L.E. and McCormick, G.C. Measurements of the backscatter matrix of dielectric spheroids. IEEE Trans. Antennas Propag. AP-26(4): 579-587; 1978.

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